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Review Article: "Flood damage assessment on agricultural areas: review and analysis of existing methods"

Pauline Brémond[1], **Frédéric Grelot**[1], **and Anne-Laurence Agenais**[1]

[1]IRSTEA, UMR G-eau, Montpellier, France

Abstract. In Europe, economic evaluation of flood management projects is becoming a commonly used decision tool. At the same time, flood management policies shift towards new concepts such as giving more room to water by restoring floodplain and living with floods. Agricultural areas are particularly targeted by these policies since they are more frequently located in floodplain areas and are considered less vulnerable than other assets such as cities or industries. Since additional or avoided damage on agriculture may have a high influence on the efficiency of these policies, flood damage assessment on agricultural areas becomes an issue to tackle.

This paper reviews existing studies addressing the question of flood damage on agriculture. Based on 41 studies, which can be qualitative or quantitative approaches, we propose a conceptual framework to analyze evaluation methods. Then, 26 studies which propose a method to evaluate agricultural damage are analyzed according to the following criterias: types of damage considered, influencing flood parameters chosen and monetized damage indicators used.

The main findings of this review are that existing methods focus mainly on crop damage and do not allow correct evaluation of new flood management policies. Finally, future research challenges and recommendations for practitioners are highlighted.

Keywords. Damage assessment, Flood, Cost-Benefit Analysis, Agriculture

1 Introduction

New flood management policies consist in giving more room to water by restoring floodplains or creating polder and retention areas, which may also require assets to be adapted to flood risk (Johnson et al., 2007). The economic evaluation of these policies requires: on the one hand, precise hydraulic models to evaluate hydraulic consequences in terms of water height, duration and speed; and on the other hand, accurate damage models reflecting asset vulnerability in order to appraise the socio-economic consequences.

More specifically, when it comes evaluating project to mitigate asset vulnerability, the project may have no impact on hydraulic parameters. Then, all benefits arise from mitigating direct damage and enhancing recovery of concerned assets. A lot of work has been carried out on hydraulic modeling to improve risk assessment (Bouwer et al., 2009). But, as argued by Merz et al. (2010), the need to improve the assessment of flood damage is an ongoing concern.

For the assessment of flood damage, different economic sectors are usually distinguished to establish damage functions. Among these sectors, agriculture is frequently considered as of minor importance compared, for example, to industrial or residential sectors because for a same exposure total damage may be comparatively lower (Merz et al., 2010).

However, considering the new flood management policies, agricultural areas may play a major role. Historically, floodplains have attracted agricultural activities because they have fertile soils. And, protection levels for agricultural areas are generally lower than for urban areas. Floodplain restoration generally implies that agricultural land will be more exposed to flooding in order to protect urban areas (Posthumus et al., 2009). Living with floods consists in adapatating assets that will not be protected by mitigating their vulnerability. Then, assessing agricultural damages becomes a real issue to determine the economic efficiency of these policies. To do so, as pointed by Posthumus et al. (2009), there is a clear need to ensure that the characteristics of agricultural activities that make them particularly vulnerable are accurately considered in economic methods to assess flood damage.

In Europe, projects concerning agriculture have long been drainage or flood protection projects. They aimed at increasing agricultural yields by improving field drainage conditions

Correspondence to: P. Brémond
(pauline.bremond@irstea.fr)

to help to meet food supply policy objectives (Morris, 1992). These projects had globally positive impacts on agriculture and they could be easily evaluated by the increase in revenue due to yield increase. The shift towards new policies requires determining if existing methods to evaluate agricultural damage are suitable for economic evaluation of those policies. To this end, the objectives of this article are:

- to review methods of assessing flood damage on agriculture;
- to analyze their accuracy to appraise flood management policies;
- to identify future research needs;
- to recommend for future methodological developments.

2 Conceptual framework

2.1 Flood damage classification

Whereas they are often indifferently used in the litterature, we make a clear distinction between the words impact, damage, and cost. In this article, we consider that flood impacts are any effects flood may have on the system considered, damage is a restriction to the negative impacts, and costs are the evaluation in monetized term to some damage.

A typology of costs has recently been established by research consortium CONHAZ for several natural hazards including flooding (Meyer et al., 2012). From this typology, we will exlcude the costs of risk mitigation, which are not directly linked to some damage. As other types of costs are directly linked to damage characteristics, we use it to clarify the grid of analysis we used for the purpose of our review article.

Following Meyer et al. (2012), a first distinction can be done between tangible and intangible damage. Tangible damage is defined as an impact that can be easily quantified. By opposition the quantification of the intangible is considered as not possible, or not easily measurable, such as environmental impacts such as biodiversity loss, aesthetic impacts; or health impacts such as injuries, stress, anxiety. Thus, intangible effects are very often not taken into account in monetary evaluation of damage (Lekuthai and Vongvisessomjai, 2001). According to CONHAZ consortium, costs of the intangible impacts may not be evaluated by market based approaches. Our paper focuses mainly on tangible damage. For a review of cost assessment methods concerning intangible effects of natural hazard, see Markantonis et al. (2012).

A second distinction is made between direct and indirect damage. This distinction is commonly accepted as a spatial distinction, direct damage corresponding to damage inside the flooded area and indirect damage corresponding to what occurs outside the flooded area (Jonkman et al., 2008). This distinction may be blurred when for damage that is induced in time to an exposed asset, the word indirect damage is also used. For more understandability, the words instantaneous and induced damage will be used to designate this distinction in this article. CONHAZ consortium (Bubeck and Kreibich, 2011) proposes another distinction considering separately losses due to business interruption, defined as damage resulting from the immediate impact of the hazard but that is not physical damage on exposed assets.Even though interesting, this distinction will not be used in the following. Based on the recommendation of Merz et al. (2010) to consider spatial and temporal scales to analyze flood damage, we propose to distinguish for tangible damage:

- instantaneous and induced damage depending on whether they occur directly after the flooding or later in time;
- direct and indirect damage depending on whether they are related to direct exposure to flooding or whether they occur on a area that has not been exposed to flooding.

Thus, four damage categories of tangible damage can be distinguished as illustrated by examples on table 1:

- direct instantaneous damage;
- direct induced damage;
- indirect instantaneous damage;
- indirect induced damage.

These damage categories are not always cited in this way in studies reviewed, but the various categories of agricultural flood damage considered can be reorganized according to this classification.

2.2 Categories of flood damage on agriculture

To illustrate each category of flood damage, examples concerning agriculture are given in table 1.

2.2.1 Direct instantaneous damage

Most of the studies reviewed focus on direct instantaneous damage, and some assess only these damage. Inside this category, several classification are proposed. Generally, agricultural assets are subdivided in several components: i) crops and vegetables, ii) farmland, i.e. soil, iii) farm buildings and its contents (stocks and machinery), iv) cattle, and v) infrastructure (e.g. lanes).

To describe possible damage on those components in further details, based on qualitative and semi qualitative studies on flood impact on agriculture (Pivot et al., 2002; Neubert and Thiel, 2004; Bauduceau, 2004a; Twining et al., 2007; Posthumus et al., 2009), seven subcategories of direct instantaneous damage can be distinguished (component to which they are linked is indicated in brackets):

Table 1. Flood damage classification

	Instantaneous (just after flooding)	Induced (later after flooding)
Direct (due to flood exposure)	– human fatalities – damage / destruction of economic goods – emergency costs – fatalities to livestock – damage / destruction of infrastructure	– loss of added value due to damage on factors of production – rehousing of households – relocation of livestock
Indirect (not directly due to flood exposure)	– increase in travel time due to damage on infrastructure – delay or cancellation of supply from the flooded area (inputs, machinery...)	– loss of added value due to business interruption of assets in the flooded area – loss of added value due to damage on infrastructure

- crop loss and yield reduction (component i);
- damage or destruction of the perennial plant material (vineyard, orchard) (component i);
- damage on soil (erosion, debris and litter deposit, contamination) (component ii);
- damage on buildings (component iii);
- damage on machinery and equipment (component iii);
- damage on stocks (inputs and products including loss of conserved grass) (component iii);
- fatalities and injuries on livestock (component iv).

Damage on infrastructure is rarely precisely assessed but it is mentionned or globally described in some studies (Du Plessis and Viljoen, 1997; Hoes and Schuurmans, 2006; Förster et al., 2008).

Moreover, some studies (Bauduceau, 2004a; Posthumus et al., 2009; Berning et al., 2000) mention that the yield reduction may cause some variations in production costs: savings due to a decrease in yield (e.g. reduction of time dedicated to some tasks) or on the contrary, increase in production costs (additional inputs to limit losses).

Lastly, the realisation of some tasks can modify initial damage. This is the case of livestocks evacuation that can reduce fatalities and injuries on animals. Another example is the resseeding of the same crop or of a new one depending on the calendar: loss of the initial crop would be total but a new production would be obtained. So these actions generate savings or new income but also new expenses that have to be assessed.

2.2.2 Direct induced damage

Concerning direct induced damage on agriculture, impacts that can be considered depend on the scale at which agricultural activities are studied. When agriculture is studied only through land use (i.e. parcels and farm buildings separetly), few direct induced damage can be taken into account. For instance, Du Plessis and Viljoen (1997) and CA30 (2009) integrate future loss yield that would occur during years after flooding when perennial plant material is destructed. Specifically concerning cattle, some studies (Morris and Hess, 1988; Posthumus et al., 2009) mention, but do not estimate, direct induced damage such as reduced milk production or increase in treatment costs of diseases due to consequences of stress for animals.

When farms are studied as a whole (i.e.considering links between parcels, buildings, machinery), empirical studies point some disturbance of farm activity due to the flood. For example, a mulcriteria analysis of farm vulnerability to flooding (Barbut et al., 2004) based on empirical work carried out by Bauduceau (2004b), showed that one of the criteria that explains better the vulnerability is the overwhelming increase of work resulting from recovery tasks. Pivot et al. (2002) also highlight the fact that beyond direct damage on elementary assets, damage at farm scale may differ depending on farm internal organization, on the availability of production resources and on farm decision making. Posthumus et al. (2009) confirm that, at farm scale, flooding can induce delay in harvesting or other field operations on non flooded plots if machinery is not available or if there is too many tasks to do at the same time. Moreover, they mention that flood may have pluriannual effects by modificating crop rotation. For instance, due to impossibility to prepare soil, it may be also impossible to sow the next crop in time.

However, these qualitative analyses do not propose method to evaluate this damage. Brémond (2011), in her PhD, proposes a method to assess direct induced damage on farm activity, considering availabilty of labour force, technical capital, cash and possibility to receive external help.

2.2.3 Indirect damage

To consider indirect damage, the scale to be considered is larger than farm scale, i.e regional or national scale.

Some qualitative studies mention possible impacts of flooding on the agricultural activities non located in the flood plain area (Bauduceau, 2004b; Brémond et al., 2008). For instance, farmers who are not directly impacted may suffer disruption in input supply (including conserved grass) if these activities have been impacted. Close economic sectors can also be disrupted even if they are not directly impacted by the flood: if harvest have been destroyed food industry may suffer shortage depending on the substitutability of the product on markets.

3 Review of methods

Studies aiming more or less specifically at assessing agricultural damage have been reviewed and are all listed in the table 2. Even if the review aims at being exhaustive, languages were a clear obstacle to this. Local literature which has not been cited in an English document may have been missed out.

3.1 General presentation of the studies

The studies listed are not independent, that is to say that each study does not present a completely different methodology. Generally, within the same country, some studies are clearly related and show the methodological evolution of a group of researchers or experts.

For instance, in the United Kingdom, Morris and Hess have contributed to the improvement of the assessment of agricultural damages. Their model, SCADE (Silsoe College Agricultural Drainage Evaluation Model), was first developed to appraise damages due to excess of water in soil and then adapted to flood. This method has been applied and adapted to several case studies in United Kingdom (Morris and Hess, 1988; Hess and Morris, 1988; Dunderdale and Morris, 1997a,b; Morris et al., 2000, 2004a,b). Those improvements were associated to the methodological research on flood damage assessment carried out by the FHRC (Flood Hazard Research Centre) and supported by the Department of Environment, Food and Rural Affairs (DEFRA), formerly Ministry of Agriculture, Fisheries and Food (MAFF). Finally, this joint research effort has resulted in the publication of a set of guidelines for economic assessment of flood management projects (Penning-Rowsell and Chatterton, 1977; Parker et al., 1987; Penning-Rowsell et al., 1992; Riddel and Green, 1999; Penning-Rowsell et al., 2005).

In Germany, the work carried out by Förster et al. (2008) to assess the efficiency of a rural retention project was part of a wider project named MEDIS (Methods for the Evaluation of the Direct and Indirect Flood Losses). This project has been conducted between 2005 and 2008 and aimed at improving approaches for flood loss estimation where researchers from several German research institutes were involved.

In France, a part of the studies comes from agricultural technical institutes. For instance, in Bourgogne French region, the regional agricultural institute has developed a methods based on the compilation and adaptation of older various studies (Pierson et al., 1994). This methodology has then been applied and completed on a smaller scale in the Saône-et-Loire French department (Dury and Didier, 2006). The institute in charge of the implementation of water management plan of the Loire River has developed another method (Devaux-Ros, 2000) that has been then adapted for the Rhône River area (SIEE et al., 2003). More recently, another methodology has been proposed by agricultural experts from the French department Gard (CA30, 2009), that aims at integrating further damage categories and at describing more in details damage considered. Somes studies were conducted in other French areas such as Citeau (2003) or Bournot (2008) but are not sufficiently documented to be included in the detailed review. The studies conducted on the Loire, the Rhône and the Saône-et-Loire rivers are very context specific. But they have some reciprocal influences on studies conducted by applied research institutes. Studies developped by research institutes are linked to a general goal to improve flood damage assessment methods (Deleuze et al., 1991; Torterotot, 1993; Erdlenbruch et al., 2007; Blanc, 2008; Blanc et al., 2008, 2010; Agenais, 2010; Brémond, 2011). Blanc et al. (2010) and Brémond (2011) are specifically dedicated to the development of a methodology to assess flood damage on agriculture. Agenais (2010) is dedicated to the development of a methodology to assess marine submersion damage on agriculture within the framework of a more global research project about marine submersion due to sea level rise in the Languedoc-Roussillon French Region. In some of these studies, some relatively old agronomic experiments results (Poirée and Ollier, 1973; Duthion, 1982) are used as references to construct crop damage functions since no more recent experiments have been conducted.

In France, a quite atypical approach, the Inondability Method (Gilard, 1998), has been developped. It enables to define Maximal Acceptable Risk for each asset category in order to identify high and low risk areas and optimize flood distribution on a territory. The asset vulnerability is defined, based on interviews and expert knowledge, by the return period and hazard parameters beyond which the hazard is qualified as unacceptable. If this method can help a critical analysis of damage function, it is not useful to appraise damage for two reasons: on the one hand, because the binary discontinu-

Table 2. Presentation of used studies in the review

Author	Country	Year	Application	Focus	Language
Gayler et al. (2001)	Australia	2001	—	Methodology	English
Goulter and Morgan (1983)	**Canada**	**1983**	**Wilson Creek, Manitoba**	**Application**	**English**
Satrapa et al.	**Czech republic**	**2012**	**—**	**Agricultural Damage**	**Czech**
Duthion (1982)	**France**	**1982**	**—**	**Methodology**	**French**
Deleuze et al. (1991)	**France**	**1991**	**—**	**Methodology**	**French**
Torterotot (1993)	France	1991	Orb	Agricultural Damage	French
Pierson et al. (1994)	**France**	**1994**	**—**	**Methodology**	**French**
Devaux-Ros (2000)	**France**	**2000**	**Loire Moyenne**	**Methodology**	**French**
SIEE et al. (2003)	**France**	**2003**	**Rhône**	**Methodology**	**French**
Dury and Didier (2006)	France	2006	Saône-et-Loire	Methodology	French
Erdlenbruch et al. (2007)	**France**	**2007**	**Orb**	**Agricultural Damage**	**French**
Blanc et al. (2008)	**France**	**2008**	**Touloubre**	**Agricultural Damage**	**French**
Blanc (2008)	France	2008	Touloubre	Agricultural Damage	French
CA30 (2009)	**France**	**2009**	**Rhône**	**Methodology**	**French**
Agenais (2010)	**France**	**2011**	**Languedoc-Roussillon**	**Methodology**	**French**
Brémond and Grelot (2010)	France	2010	Rhône	Methodology	French
Brémond (2011)	**France**	**2011**	**Rhône**	**Methodology**	**English**
Neubert and Thiel (2004)	Germany	2004		Methodology	German
Förster et al. (2008)	**Germany**	**2008**	**Elbe**	**Agricultural Damage**	**English**
Poirée and Ollier (1973)	**Hungary**	**1948**	**—**	**Methodology**	**French**
Dutta et al. (2003)	**Japan**	**2003**	**Ichinomiya**	**Agricultural Damage**	**English**
MLIT (2005)	Japan	2005	—	Methodology	Japanese
Hoes and Schuurmans (2006)	**Netherland**	**2006**	**Westeramstel area**	**Application**	**English**
Jonkman et al. (2008)	**Netherland**	**2008**	**Souh Holland**	**Application**	**English**
Du Plessis and Viljoen (1997)	**South Africa**	**1997**	**—**	**Methodology**	**Afrikaans**
Du Plessis and Viljoen (1998)	South Africa	1998	Orange river area	Agricultural Damage	English
Du Plessis and Viljoen (1999)	South Africa	1999	Orange river area	Methodology	English
Consuegra Zammit (1992)	**Switzerland**	**1992**	**Broye**	**Agricultural Damage**	**French**
Morris and Hess (1988)	**UK**	**1988**	**South West England**	**Methodology**	**English**
Hess and Morris (1988)	UK	1988	South West England	Methodology	English
Dunderdale and Morris (1997a)	**UK**	**1997**	**River Wensum**	**Agricultural Damage**	**English**
Dunderdale and Morris (1997b)	UK	1997	River Wensum	Agricultural Damage	English
Morris et al. (2000)	UK	2000	East England	Agricultural Damage	English
Morris et al. (2004a)	UK	2004	England	Agricultural Damage	English
Morris et al. (2004b)	UK	2004	England	Agricultural Damage	English
Penning-Rowsell et al. (2005)	**UK**	**2005**	**—**	**Methodology**	**English**
Lacewell and Eidman (1970)	USA	1970	—	Agricultural Damage	English
McDonald (1970)	**USA**	**1970**	**gladstone -Kinchela**	**Application**	**English**
Lacewell and Eidman (1972)	**USA**	**1972**	**Nuyaka Creek floodplain**	**Agricultural Damage**	**English**
USACE (1985)	**USA**	**1985**	**—**	**Methodology**	**English**
Lacewell et al. (2006)	**USA**	**2006**	**Willacy County, Texas**	**Methodology**	**English**

ous functions are much too simples in an economic appraisal, second, because no economic indicators are proposed.

In USA, research on flood and excess of water damage to agriculture has been long carried out notably by Lacewell and Eidman (1970, 1972) and USACE (1985). An application in USA has also been carried out by McDonald (1970). Specific attention has been paid to agricultural damage since floodplain restoration were under discussion in USA before in Europe. AGDAM (Agriculture Flood Damage Analysis) is a methodology which has been developed by the US Army Corps of Engineers (USACE, 1985). This methodology is included in a wider software, HEC-FDA (Hydrologic Engineering Center - Flood Damage Analysis) which aims at evaluating flood management projects.

In Japan, a national guide exists but only in japanese (MLIT, 2005) and is used on a case study by Dutta et al. (2003).

In Australia, a national guide also exists (Gayler et al., 2001) but no application on real case study has been found.

In South Africa, Du Plessis, Viljoen and Berning (1997; 2000) have developed a specific component for agriculture included in a wider flood damage simulation model (FLOD-

SIM). Damage functions have been built for several crops and then the method has been applied on a real case study (Du Plessis and Viljoen, 1998). Although the methodology seems interesting, the first article is in afrikaans, which constitutes an obstacle to its full comprehension.

In the Netherlands, Hoes and Schuurmans (2006) and Jonkman et al. (2008) present results of economic assessment of flood management projects and use damage functions for agriculture, but no methodological details are given and no national recommendation has been found in English.

According to Meyer and Messner (2005), Satrapa and Horsky are identified as Czech researchers experts in flood damage modelling and some damage functions that they developed for agriculture are presented. Unfortunately, original studies we found of these authors are written in Czech (Satrapa et al.).

Some more isolated studies are also analyzed. Goulter and Morgan (1983) evaluated flood management on a rural area in Canada. But, few attention has been paid to the method used to appraise agricultural damage. In Switzerland, Consuegra Zammit (1992) analyzed in his PhD, flood management projects in a framework close to Inondability method. In the application on the Broye watershed, he details the method used to assess damage on agriculture and specifically tackles the question of seasonality and crop rotation.

3.2 Characteristics and objectives of the studies

Even focusing on the same topic, the studies listed above differ according the weight given to agricultural damage assessment comparing to others sectors which is also related to their objectives. For each study, these characteristics are given in table 2.

Not all the studies focus only on agricultural damage. Although frontiers are sometimes not totally clear, three categories can be distinguished depending on the focus on and interest paid to agricultural damage. Some studies aim at presenting a methodology to assess agricultural damage (marked as *methodology* in the focus colmun in table 2). This kind of studies can be part of wider methodological guides to appraise flood damage on other sectors and/or damage due to other natural hazards. Those studies usually refer to other studies at least from the same country and often have led to specific methodological development. Some other studies propose an important focus on agricultural damage (marked as *Agricultural Damage*), in the framework of a project evaluation, because this sector may have a critical weight in the project implementation. They often use adaptations of existing methodologies. At last, some other studies only apply existing agricultural damage functions (marked as *Application*), giving few details on their origins.

It is also necessary to point out that under the word flood, several hazard types can be grouped together, e.g. inundation by submersion, waterlogging due to bad drainage conditions, coastal flooding due to inundation by salted water. Our focus is on inundation by submersion but some studies have first focus on waterlogging before adapting the method to inundation by submersion (Morris and Hess, 1988; Poirée and Ollier, 1973). Salty water can affect affect crop quality and cause a decrease in their selling prices. It is notably the case for meadows and Pierson et al. (1994) mentions the consequences in terms of food completion for cattle but do not propose functions to assess it in monetary terms.

In the following,studies reviewed are analyzed more in detail considering several criteria:

- the damage categories considered,
- the hazard parameters used in damage functions,
- the economic indicators used to monetize damage for each components.

To perform this analysis, we selected the studies which are are significatively different from others and which propose or use quantitative damage functions. Even proposing some methodology to assess several damage categories, Neubert and Thiel (2004) and Gayler et al. (2001) do not really propose quantitative damage functions and are excluded in this review. Then, the folowing review consider 26 studies, i.e. the one in bold in table 2. In the following sections, studies are described through every criteria and then a short analysis is proposed.

3.3 Damage categories considered

3.3.1 Direct damages

Direct damages can be analyzed by considering which farm components may be affected by flood hazard. As shown on table 3 and according to the list in section 2.2.1, the farm components considered are crop, cattle, building, machinery, soil, stock, and plant material. The diversity between the 26 reviewed studies concerning which farm components are considered is important. Details are given in the following paragraphs.

First, in the table 3, it is shown that all the studies take into account crop damage. A more detailed analysis shows that only 19 consider several crop types. Within these 19 studies, CA30 (2009), Agenais (2010) and Consuegra Zammit (1992) even consider the fact that crop types may change on a plot (crop rotation). In Erdlenbruch et al. (2007) and McDonald (1970), simplification to two types are made. Morris and Hess (1988) focus on pasture and Duthion (1982) on maize. However, in Hoes and Schuurmans (2006) and Jonkman et al. (2008), the crop type corresponding to the damage function used in the study is not specified. In USACE (1985) which is more a methodological approach, no crop damage functions are directly given. We discuss, in subsection 3.5.1, the indicators used to assess crop damage.

The second important damage category is damage to buildings and their contents. Nine methods consider damage

Table 3. Farm components considered in direct damages estimation for the reviewed studies

Author	Crop	Cattle	Building	Machinery	Soil	Stock	Plant Material
Goulter and Morgan (1983)	yes	no	no	no	no	no	no
Satrapa et al.	yes	no	no	no	no	no	no
Duthion (1982)	yes	no	no	no	no	no	no
Deleuze et al. (1991)	yes	no	no	no	no	no	no
Pierson et al. (1994)	yes	no	no	no	no	no	no
Devaux-Ros (2000)	yes	yes	yes	yes	no	no	yes
SIEE et al. (2003)	yes	no	yes	yes	no	no	yes
Erdlenbruch et al. (2007)	yes	no	yes	no	no	no	no
Blanc et al. (2008)	yes	no	yes	no	no	no	no
CA30 (2009)	yes	no	no	yes	yes	yes	yes
Agenais (2010)	yes	no	yes	no	yes	no	yes
Brémond (2011)	yes	no	yes	yes	yes	yes	yes
Förster et al. (2008)	yes	no	no	no	no	no	no
Poirée and Ollier (1973)	yes	no	no	no	no	no	no
Dutta et al. (2003)	yes	no	yes	yes	no	no	no
Hoes and Schuurmans (2006)	yes	no	yes	no	no	no	no
Jonkman et al. (2008)	yes	no	no	no	no	no	no
Du Plessis and Viljoen (1997)	yes	no	yes	no	yes	no	yes
Consuegra Zammit (1992)	yes	no	no	no	no	no	no
Morris and Hess (1988)	yes	yes	no	no	no	no	no
Dunderdale and Morris (1997a)	yes	no	no	no	no	no	no
Penning-Rowsell et al. (2005)	yes	no	no	no	no	no	no
McDonald (1970)	yes	no	no	no	no	no	no
Lacewell and Eidman (1972)	yes	no	no	no	no	no	no
USACE (1985)	yes	no	no	no	no	no	no
Lacewell et al. (2006)	yes	no	no	no	no	no	no

to agricultural buildings (sheds and/or greenhouses). But, within these studies, some do not really propose or use specific damage functions for agriculture and consider damage to agricultural buildings as one to domestic buildings (Blanc et al., 2008; Erdlenbruch et al., 2007). Only four methods, i.e Brémond (2011),Dutta et al. (2003), SIEE et al. (2003) and Devaux-Ros (2000) explicitely propose damage functions for agricultural buildings specifically adjusted to farm activity. Moreover, in SIEE et al. (2003) and Devaux-Ros (2000), damage on buildings include damage to machinery. Then, several damage functions for agricultural buildings are defined depending on crop specialization. Two other studies define damage to machinery separately from building damage: CA30 (2009) and Brémond (2011). These two studies are also the only ones proposing damage functions for stocks stored in buildings.

Four studies propose to evaluate damage on land plot soil. It mainly includes costs of restoring works in case of soil erosion and of cleaning soil from deposits.

Two studies evaluate damage to cattle with different approach: Devaux-Ros (2000) and Morris and Hess (1988). Devaux-Ros (2000) proposes to evaluate the cost of fatalities and loss of production on cattle due to flooding. Morris and Hess (1988) consider there is no fatalities on cattle but an increase in feeding costs due to the decrease in nutritional quality of pasture. This damage is classified, in our framework, as an induced damage (see subsection 3.3.2).

Depending on the crops studied, damage to plant material can be important to consider. It concerns perennial trees or plants such as vineyard, orchard or sugar cane. Some damage functions have been developed in France, in the mediteranean context (SIEE et al., 2003; CA30, 2009; Agenais, 2010; Brémond, 2011) or on the Loire River (Devaux-Ros, 2000) and in South Africa (Du Plessis and Viljoen, 1997). Taking into account impacts on plant material, these studies consider loss of income during several years, that is an induced damage (see subsection 3.3.2).

3.3.2 Induced damage

As said in section 2.2.2, most of induced damage can be defined only if the study is conducted at farm scale. As well as other economic activities, farm may endure perturbation or disruption of their activity due to the flood. In the reviewed studies, farm scale is rarely considered and, as a consequence, induced damage on farm functioning is rarely taken into account although quantitative studies, mentioned in subsection 2.2.2, point this.

Morris and Hess (1988) developed a method to assess induced damage specific to husbandry farming. This method propose a comprehensive modelling of the relation between flooded pastures and the consequences on cattle growing. The damage on agricultural product is assessed by the additive costs required to keep on feeding and housing cattle due to grassland and building damage. Pierson et al. (1994) also mentions those induced damage but do not propose functions to assess them. For instance, some induced impacts considered in those studies are:

- extra purchase of feed,
- relocation of cattle,
- cost to secure water for livestock if disruption of potable water supplies.

For crops, Lacewell et al. (2006) propose to update the method they initially developed in 1972 by integrating increase in production costs induced by flooding such as additive phytosanitary treatments or additive field operations. Those additive costs were defined based on interviews with farmers for several crop types.

Brémond (2011) developed a method to appraise induced damage on farm activity due to increase in workforce needs due to recovery task (cleaning, repairing...) and to damage on machinery. This thesis needed a big and very detailed work to assess the delay to recover possibility to conduct crops normally at farm scale and to estimate the potential incompatibility and priority between repairing tasks and agricultural tasks depending on farmers access to external resources (workforce, material, cash).

3.3.3 Indirect damage

As said in the section 2.2.3, very few studies describe indirect damage and even fewer propose to assess it. Du Plessis and Viljoen (1999) proposes a calculation of the secondary effects of floods in the lower Orange River area, which correspond to indirect damage, at a regional and national scale. Consequences on agricultural and commercial sectors are assessed, taking also into account impacts on labour market.

3.3.4 Obstacles to consider all damage categories

Concerning direct damage, a consensus exist on the necessity to consider crop damage even if the accuracy vary a lot among existing studies. Concerning damage on agricultural buildings, assuming that damage function for domestic and agricultural building could be the same seems really simplistic and may induce huge errors on damage evaluation depending on the number of agricultural buildings located in the flood plain area. In practice, this simplification as well as the simplification done on the diversity of crop types mainly comes from a lack of data on landuse characterisation and is not related to a lack of method in economics to assess damage. Using damage functions for different crop types and different agricultural buildings require to define a typology and then to be able to locate them in the flood plain area. The more the typology is accurate, the more land use characterization need to be accurate. The lake of studies taking into account induced damage is caused by the same issue of data disponibility. In fact, it is often difficult to spatially identify plots and buildings belonging to a farm and to obtain individual data on them (machinery, stocks, workforce...). Although these issues may be difficult to tackle when it comes to evaluate a project due to the difficulty to locate and to link assets, this should not prevent methodological research to develop damage functions.

3.4 Hazard parameters

Direct damages can also be analyzed by considering which hazard parameters may be the most influencing on farm component damage. As it is shown on table 4, the hazard parameters considered are the season of occurence of the flood, the height of water, the duration, the velocity of current, deposit, contamination by pollution and salinity of water.

3.4.1 Period of occurrence

The great majority of the studies, i.e. 23 out of the 26, take into account seasonality to assess crop damage. Only three studies do not consider the period of occurrence, i.e. Goulter and Morgan (1983), Hoes and Schuurmans (2006) and Jonkman et al. (2008). But, in these studies, damage to agriculture is not the main focus. Most of the time, the period of occurrence is considered by defining different damage coefficients for every year period. All the reviewed studies take the year as refence for time scale. Then, steps can be monthly or crop specific periods.

For other damage categories, the period of occurrence may not be as important as for crop damage except for damage to plant material. Indeed, all the studies that consider damage to plant material also take into account the period of occurrence in damage functions. Brémond (2011) also consider the period of occurrence to assess damage to stocks.

To sum up, it is a common agreement among reviewed studies that seasonality is an essential parameter to be considered to define crop damage and also damage to plant material. Although, it is to be noted that all the reviewed studies take the year as time scale in damage functions. This choice implies a serious problem for damage function transferability due to high variability of crop vegetative cycle depending on climatic conditions. For instance, it would be seriously questionable to use crop damage functions developed in Northern Europe in Mediterranean areas. As an example, wheat is harvested in July in Southern Europe whereas the harvest can be done until the end of August in Northern Europe depending on climatic conditions. Then, it seems crucial to turn methodological developments towards a design of crop damage functions based on crop vegetative cycles. Then, the time steps can be derived for every country based on the crop vegetative cycle which allows the transferability and mutualization of research efforts.

3.4.2 Height of water

The second flood parameter considered in damage functions is the height of water. 20 studies consider this parameter to assess crop damage. It is generally the only parameter considered to assess damage on building and contents when it is taken into account. This parameter is also taken into account to evaluate damage to plant material and sometimes on soil.

3.4.3 Duration

Most of the studies (16) also consider duration to appraise crop damage and damage on plant material. The time step usually considered is the number of days of submersion. It is difficult to know in existing studies if the duration of submersion corresponds to the real duration of the flood or includes also soil drying of the agricultural plots. This drying time may vary a lot depending on soil structure and it would be more accurate to use real duration of submersion in standard damage function and then to adapt the duration of soil drying by considering at the local level soil texture. Agenais (2010), in her study, takes into account soil texture because drying duration is a main parameter to assess impacts of salinity on soil. In fact, for the same flood duration, damage on soil and crop are significatively diferent depending on soil texture. Moreover, flood duration is not always simulated in basic hydraulic modelling. Then, when economic assessments of agricultural damage are to be done, it should be specifically specified before launching hydraulic analysis that duration is a parameter needed.

3.4.4 Velocity

Only six methods consider flow speed to assess crop damage. All these studies use qualitative thresholds to define flow speed, e.g. low, medium, high speed, in damage functions. This parameter is also considered by the majorities of authors who build damage functions on plant material because of potential diggingout (Brémond, 2011; CA30, 2009; Devaux-Ros, 2000; SIEE et al., 2003) and on soil for its potential impacts in terms of erosion (Brémond, 2011; CA30, 2009).

As for flood duration, flow speed is not always simulated in classical hydraulic modelings. Then, hydraulic simulations integrating an analysis of flow speed should be requested in advance if crop damage functions which consider this parameter are chosen. In practice, the necessity to consider flow speed mainly depends on the type of flood locally considered. For instance, if locally most of the flooding events are flash floods, it seems highly important to pay more attention to this parameter.

3.4.5 Deposit, contamination and salinity

Water with silts can settle on crops products, affecting their quality and so causing a decrease of their selling prices. It is notably the case for meadows and Pierson et al. (1994) mentions the consequences in terms of flood complement supply for cattle. USACE (1985) also proposes to take potential deposit into account to assess damage on crops.

Contamination by pollution is not taken into account in the studies reviewed. Although it is an important topic discussed when floodpalin restoration is planned, few feedback experience exists.

Salt can also cause specific impacts on crops and on soil. In case of marine submersion yield reduction are higher and induced damage are important because of the salt toxicity for soil (Agenais, 2010).

3.4.6 Combination of parameters

Usually, the studies consider a combination of several flood parameters to build damage functions. The most complex are crop damage functions. Among the reviewed studies, one to five parameters are considered. USACE (1985) propose to combine the five flood parameters: period of occurrence, height of water, duration, flow speed and deposit. Even if this study which is more methodological, do not propose complete crop damage functions, it shows that depending on the local context this parameters may have an influence on damage.

Then, Brémond (2011) and CA30 (2009) consider a combination of four flood parameters, i.e period of occurrence, height of water, duration, flow speed to build crop damage function. The majority of the studies consider a combination of two or three flood parameters to build crop damage functions.

3.5 Damage indicators

Most of the time, flood damage assessment methods rely on two main stages: 1) quantifying flood impacts, 2) expressing these impacts in monetary values (Penning-Rowsell et al., 2005). Depending on the studies details on the first step are not always presented.

The correct damage indicator for economic assessment is the loss of added value or the reparation costs for material damage. However, several economic indicators can be used as proxy for this. We analyzed how these indicators are used in the reviewed studies for crop damage and other farm components.

Table 4. Hazard parameters encountered in the reviewed studies

Author	Season	Height	Duration	Velocity	Deposit	Contamination	Salinity	Parameters
Goulter and Morgan (1983)	no	yes	yes	no	no	no	no	2
Satrapa et al.	yes	no	no	no	no	no	no	1
Duthion (1982)	yes	no	yes	no	no	no	no	2
Deleuze et al. (1991)	yes	yes	yes	no	no	no	no	3
Pierson et al. (1994)	yes	no	yes	no	yes	no	no	3
Devaux-Ros (2000)	yes	yes	no	yes	no	no	no	3
SIEE et al. (2003)	yes	yes	no	yes	no	no	no	3
Erdlenbruch et al. (2007)	yes	yes	no	no	no	no	no	2
Blanc et al. (2008)	yes	yes	no	no	no	no	no	2
CA30 (2009)	yes	yes	yes	yes	no	no	no	4
Agenais (2010)	yes	no	yes	yes	no	no	yes	4
Brémond (2011)	yes	yes	yes	yes	no	no	no	4
Förster et al. (2008)	yes	yes	yes	no	no	no	no	3
Poirée and Ollier (1973)	yes	no	yes	no	no	no	no	2
Dutta et al. (2003)	yes	yes	yes	no	no	no	no	3
Hoes and Schuurmans (2006)	no	yes	no	no	no	no	no	1
Jonkman et al. (2008)	no	yes	no	no	no	no	no	1
Du Plessis and Viljoen (1997)	yes	yes	yes	no	no	no	no	3
Consuegra Zammit (1992)	yes	no	yes	no	no	no	no	2
Morris and Hess (1988)	yes	yes	yes	no	no	no	no	3
Dunderdale and Morris (1997a)	yes	yes	yes	no	no	no	no	3
Penning-Rowsell et al. (2005)	yes	yes	yes	no	no	no	no	3
McDonald (1970)	yes	yes	no	no	no	no	no	2
Lacewell and Eidman (1972)	yes	yes	no	no	no	no	no	2
USACE (1985)	yes	yes	yes	yes	yes	no	no	5
Lacewell et al. (2006)	yes	yes	no	no	no	no	no	2

3.5.1 Crop damage

For crop damage, the loss of added value corresponds to the decrease in product less the variation of production costs due to flooding. Due to the loss of yield, some variable production costs may be saved and other may increase (supplementary treatment, operation field).

Most of the studies quantitatively estimate the percentage of yield loss in function of hazard parameters. Some studies, specifically agronomic ones, even stop the analysis at this stage. It is the case of Poirée and Ollier (1973); Duthion (1982); Pierson et al. (1994); Satrapa et al..

Usually, the variation of product is directly monetized by applying the selling price to the variation of yield. Then, some authors directly use the variation of gross product as a proxy for the crop damage. This approximation means that the variation in production costs due to flooding is neglected. Eleven studies use this indicator as a proxy for crop damage (Blanc et al., 2008; CA30, 2009; Consuegra Zammit, 1992; Deleuze et al., 1991; Dutta et al., 2003; Devaux-Ros, 2000; Erdlenbruch et al., 2007; Förster et al., 2008; Goulter and Morgan, 1983; Hoes and Schuurmans, 2006; McDonald, 1970). Contrarily, Lacewell and Eidman (1972) uses the net margin as the proxy for crop damage, that is to say that all variable costs have been saved. In the updated studies, proposed in 2006, Lacewell et al. add some additional production costs (additional treatment, tillage) in crop damage evaluation. Du Plessis and Viljoen (1997) uses the gross product less the harvesting costs.

In fact, the variation in production costs depends on the period of occurrence of the flooding. USACE (1985) recommends to consider the variation in production costs depending on the period of occurrence and to do so, it is necessary to collect data concerning the distribution of production costs over the year. Brémond (2011) developed a modelling approach that considers the crop management sequence and then can determine the variable costs saved in function of the period of occurrence. This method requires specific data on production tasks to be achieved for each crop.

SIEE et al. (2003) propose to consider only two proxy: the gross product if the flood occurs at the end of the production cycle, the gross margin if the the flood occurs at the beginning. This simplification may be acceptable if most of the flood occur at the beginning or at the end of the crop production cycle. However, it is questionable which value should be taken in between.

The MultiCouloured Manual (Penning-Rowsell et al., 2005) recommends to use the gross margin to evaluate crop damage and to adjust this with variable costs that have been committed and cannot be saved in the event of a flood. Thus, the gross margin estimate should be increased accordingly. This proxy is also used in Dunderdale and Morris (1997a).

To sum up, the reviewed studies use several economic indicators depending on how the variable production costs are considered to be impacted by flood events. A really precise estimate of variable costs variation requires to know the distribution of production costs over the year. Moreover, if numerous flood events are simulated for several period of occurrence, the calculations should be automated. Concerning subsidies, it is a common agreement in economics, to consider that the loss of subsidy, for example for farmers, should not be considered as a loss of product in the evaluation of the economic damage because it is a transfer and not a real loss.

3.5.2 Damage indicators for the other farm components

When material damage on farm components other than crop, i.e. damage to soil, building, machinery, stocks, is evaluated, the economic indicator used is the reparation cost. These reparation costs are evaluated by the cost of actions necessary to recover a status equivalent to the one before the flood event occurred.

Damage to soil is evaluated by cleaning costs and additional tillage, gap filling that must be achieved depending on flood intensity. Among the only two methods that consider soil damage, CA30 (2009) uses an aggregated indicator which do not allow to know which recovery tasks are included in soil damage. Contrarily, Brémond (2011) details these tasks which allow adaptation of the methodology to local context. Damage to agricultural buildings is usually evaluated by cleaning costs. Concerning damage to machinery, damage are evaluated by the reparation or re buying costs. But, monetization requires to determine which value should be considered as an economic damage between actual cash value and depreciated value. CA30 (2009) proposes to account for the age of machinery pool to define a depreciation rate. It is also the assumption made by Brémond (2011) to evaluate damage to machinery.

For studies which consider damage to plant material, the damage is usually evaluated by replanting costs and loss of added value before the orchard or vine recover the same production potential.

4 Analysis

4.1 Comparing qualitative and quantitative works

The review carried out showed that a gap exists between qualitative studies and quantitative studies. All qualitative studies point that flood damage on agriculture include besides crop damage, damage to other farm components such as soil of land plots, building and contents. Moreover, they often point out that the appropriate scale to analyze damage to agriculture is the farm scale because some induced damage on farm activity may occur after flooding especially because of work organization disturbance.

On the other hand, most of the quantitative studies reviewed use more or less important simplifications. The simplifications encountered are:

1. considering few damage components, sometimes only crop damage,
2. simplifying the number of influencing parameters to design damage functions,
3. simplifying crop diversity,
4. considering agricultural buildings as domestic ones,
5. using proxy for the loss of added value,
6. considering farm components as separated, and not linked at farm level

Those simplications may have different sources.

As we have shown in subsection 3.1, most of exchanges on methodology seem limited to the national level and few research is carried out on the transferability of local methodologies. One of the main difficulties for these exchanges is related to language, as development are very often related to technical studies, written in native languages. Even at national level, exchanges between research and practitioner communities would improve the quality of economic evaluation. Thus, it appears a lack of exchanges at international level, which is not a stimulating context for the development and diffusion of knowledge.

Simplifications may also be related to an adpatation of methodologies to fit the availabilty of data. For instance, to evaluate crop damage, damage functions must correspond to crop typology used in landuse description. But, most of the time, classical landuse database do not provide such a detailed crop typology. The same problem can be encountered for the localization and typology of agricultural buildings. Moreover, one difficulty may also be related to the attribution of a value for every agricultural building type.

Considering the monetized damage indicators, rigorous methodologies exist and it is clear that the economic damage should be evaluated by the loss of added value. For crop damage, this implies to consider in function of the period of occurrence the variation in variable production costs. In practice, to calculate the loss of added value requires to know farmers' practices and the distribution of production costs over the year for each crops. Moreover, it requires powerful computational programs to calculate for every potential period of occurrence and every crop potential impacted, the loss of added value.

Flood parameters to be considered to evaluate flood damage to agriculture are, a priori, specific compared to other sectors. Seasonality and duration are identified as the most influencing parameters.

4.2 Suitability to assess classical flood management policies

Cost-Benefit Analysis (CBA) relies on the comparison of two options to determine which one is the most efficient. Usually, an option, called project is compared with the do-nothing situation. For instance, a dyke will better protect some areas until a certain flood intensity. The hazard is modified after the project implementation and avoided damage resulting from this are evaluated and accounted for benefits in CBA. For structural policies suc as dykes which aim at protecting vulnerable areas (often urban ones), the simplifications on agricultural damage evaluation may not be a problem for assessing benefit to agricultural sector. However, the suitability of these methods to evaluate new flood management policies need to be discussed.

4.3 Suitability to assess floodplain restoration policies

Flood management policies such as floodplain restoration or creation of retention areas raise new issues for damage assessment, that may not be adressed in current practice. Policies of this type aim at increasing flood exposure of less vulnerable areas, often agricultural ones, to protect areas considered more vulnerable such as urban ones.

From an economic evaluation perspective, this brings two issues: efficieny and equity.

Firstly, to evaluate the efficiency of these projects, methods with comparable accuracy must allow to evaluate damage on agricultural and urban areas. Basically, the damage on agricultural areas, more exposed, represent a part of the cost of the project with implementation costs whereas avoided damage on urban areas represent the benefits. Based on the efficiency criteria, additional damage to agriculture and project implementation costs should be compensated by avoided damage on areas which benefit from higher protection, i.e. urban ones. Then, to provide a correct evaluation of this kind of project, it is crucial not to underestimate the costs of the project and to pay attention to agricultural damage evaluation.

Secondly, these policies clearly make visible losers and winners in terms of benefits and costs. Farmers who will be more exposed, will suffer more damage and urban areas will be more protected. In classical CBA, the Kaldor-Hicks compensation principle states that hypothetical compensation is sufficient to achieve a potential Pareto improvement (Pearce et al., 2006). In the case of floodplain restoration policies, that would mean that additional damage on agricultural areas do not need to be effectively compensated so that the project is considered efficient. However, the analysis of feedback experience on these policies in France, shows that real compensation is an indispensable lever for an effective implementation (Erdlenbruch et al., 2009). The difficulties to agree on compensations during the negociation process between farmers and decision makers, is one of the main barrier to the implementation. This calls for the development of methods to evaluate agricultural damage that actually reflect the damage endured by farmers.

As a consequence of the previous remarks, it is clear that the evaluation and the implementation of floodplain restoration policies require accurate methods which reflect damage endured by farmers to evaluate additional flood damage on agriculture. Existing methods tend to focus on crop damage and mainly considering two or three flood parameters. But, floodplain restoration results in complex changes of flood parameters in terms of frequency, period of occurrence, height, velocity, duration of the flood. Then, existing methods, specifically those which only consider crop damage may not be sufficient. For example, on the Rhone River downstream, the probability of occurrence of flood events is the higher in winter. At this period, the amount of crop damage is low for most of the crops. But, as shown in section 2.2, qualitative studies also highlight the importance of other damage categories, particularly, recovery and cleaning process after flooding. The work carried out by Brémond and Grelot (2010) confirm this by simulating the distribution of damage to agriculture for several parameter combinations, in particular the period of occurrence. It proves that even if crop damage is low, damage on other farm components such as soil or building and contents as well as potential induced damage on farm activity may represent a large share of the total damage.

Additionnaly, farmers may also be reluctant to accept floodplain restoration due to potential flood water contamination. The link between soil contamination and flooding is fewly investigated. The difficulty to monetize this damage is not related to a lack of economic method but lies in the necessity to better understand contamination biophysical processes occurring after flooding to be able to quantify them.

Finally, farmers may be exposed to an increased risk of bankruptcy, directly linked to flood exposure. To explore this risk, damage assessment methods needs to grasp farm as a system.

Then, using methods that only take into account crop damage, that do not consider damage seasonality may skew damage assessment results. Moreover, neglecting damage to farm components other than crop, specifically soil damage, may seem unrealistic. Those simplifications may put the brake on negotiations with farmers.

4.4 Suitability to assess vulnerability mitigation measures

For vulnerability mitigation measures, the focus is put on adaptation measures thay may lead to a mitigation of flood effects on agricultural sector. Thus, the goal of those measures is not to modify the flood hazard but to adapt the assets exposed to this hazard. From a damage assessment perspective this have a direct implication: as the asset is changing, the way its vulnerability is modelized through damage functions must be adapted to.

There is a simple case. If mitigation measures consist of changing crops cultivated in flood prone areas, damage assessment may consist in using, if available, corresponding damage functions. From an economic evaluation perspective, this may give a proxy for benefits evaluation, but the assessment of the costs of the policy will imply to explore conditions under which such a shift of crop is possible.

Most of the cases are not so simple. Very often, vulnerability mitigation measures are linked to some organization characteristics at farm level: elevation of building and contents (machinery, stocks), enhancement of farm recovery after flood event, through availability of machinery, stocks, labour, financial resources (Brémond et al., 2009). To traduce this in damage function, a sufficient understanding of how the asset works is implied. Thus, economic evaluation of vulnerability mitigation measures are rare. Kreibich et al. (2011) evaluate vulnerability mitigation measures for the domestic sector. Brémond (2011) evaluates some vulnerability mitigation measures for the agricultural sector on the Rhone River downstream. Using the model developed to evaluate direct and induced damage at farm level, Brémond (2011) carried out a CBA for height vulnerability mitigation measures on three typical farms. This evaluation showed two important conclusions. Firstly, as showed by Kreibich et al. (2011), vulnerability mitigation measures are efficient only if assets are frequently flooded, which may be the case of agricultural assets in flood plains. Secondly, it revealed that one of the most efficient measure for all typical farm consists in organizing solidarity after flood events which considerably limits induced damage on farm activity.

5 Recommendations for future research

To conclude this article, we propose four types of recommendations

1. methodological developments for agricultural damage assessment;
2. exploring the viability of farms;
3. developement of sensivity analysis;
4. adapting hazard modelling to agriculture vulnerability.

The first three types are more oriented for the scientific community, the last one for the practionners.

5.1 Needs for methodological developments

The first group of scientific challenges concerns the improvement of methodology to evaluate agricultural damage. The main challenges that emerge are the following ones:

– improvement of crop damage functions;

– development of methodologies which include the whole damage at farm level;

– contribution to a better data collection.

Even if most of research efforts have been, so far, focused on crop damage, some improvements still need to be addressed. First, to consolidate crop damage functions, further researches should be carried out on collecting, comparing and homogenizing expert knowledge on flood damage on crops and on farmers' practices after flooding. To facilitate international exchange and transferability of crop damage functions, we recommend to use the vegetative stage of growing as temporal scale. In this way, crop damage functions could be adapted in countries which have different climate. To evaluate the loss of added value due to crop damage, also requires to determine the variation in production costs. To do so, it is necessary to collect data on farmers'practices depending of crop damage; e.g. to understand if the variation in production costs is proportional to the loss of yield.

Research community should also consolidate methodology to evaluate flood damage on farm components other than crop i.e. soil, plant material, buildings and contents and induced damage on activity. Consolidating damage functions on every farm component requires to collect and analyzes expert knowledge. Concerning induced damage, the methodology developed by Brémond (2011) is a first step but need to be tested in several local contexts.

Lastly, one role of research community is to clearly express the data needed (type, aggregation level, format) for economic evaluation so that data collection could be facilitated in the aftermath of flooding.

5.2 Viability of farms

The second group of research questions concern the validity of underlying assumptions done in damage evaluation methods. All the methods reviewed use the avoided damage principle to evaluate damage, i.e. economic damage is assessed by the loss of added value or by the cost of actions done to recover to a baseline state, equivalent to the initial one, such as cleaning, repairing, re-buying.

The main underlying assumption is that the whole asset, here the farms, actually recovers to a state equivalent to the initial one. But, the risk of bankruptcy may make false this crucial assumption. A financial assessment at farm level, that takes into account loss, increase and savings in production costs, variations in subsidies as well as insurance compensations should be processed to test the assumption made on asset recovery. If this assumption is not validated, the question about future land use (other economic activities, fallow land...) and the associated damage in case of flooding should be addressed.

5.3 Sensivity analysis

The third scientific challenge concerns sensitivity analysis. Once methologies to evaluate agricultural damage exist, it is important to define really influencing parameters on the total amount of damage as well as the influence of those parameters on damage distribution e.g between direct and induced damage, between the damage to every farm components.

For example, we have shown that existing methods use different combination of flood parameter to design damage functions. Sensitivity analysis may help to select some depending on the flood type. Influencing flood parameters are certainly not the same in case of flash flood and waterlogging. The period of occurrence of the flood may also have huge impact on damage distribution. It can be assumed that, crop loss, for most crops, are high for spring or summer floods but may have relatively low share for winter flood. This does not mean farmers do not endure damage during these periods considering other damage. Specifically concerning crop damage, some other parameters may also have an influence: crop price and yield variability.

5.4 Adapting hazard modelling to agriculture vulnerability

Finally, we conclude with some recommendations to practitioners for the economic evaluation of flood management policies in which agricultural assets are an important stake such as floodplain restoration and vulnerability mitigation. In practice, economic evaluations always imply trade-off between a rigorous methodology and the resources (data, time, money) actually available to carry it out. However, to facilitate comparison of several options or projects, the best practice would be to refer to the same methodological framework and then to argument why simplifying assumptions have to be done.

Moreover, the conduct of economic evaluations require a good coordination between data collection, hydraulic and damage modelling. Concerning data collection, this is a common practice to collect hazard data for hydraulic modelling. It should be the same for asset vulnerability data and it is important to plan funding specially to do it. As the modelling of agricultural damage involve specific flood parameters such as the period of occurrence and duration, the need of these parameters should be specified. Taking into account seasonality also means to analyze flood probability of occurrence in function of the season which call for specific hydrologic models. For a good execution of economic evaluations, those requirements should be specified before launching hydrologic and hydraulic modelling.

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